Do Hipot Tests Damage Rotating Machine Insulation?

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Abstract:- **Over-potential or hipot tests have been applied for many decades to rotating machine windings to assure that the electrical insulation in windings is fit for service. Hipot tests are used universally as acceptance tests for new windings. However, a rotating machine maintenance engineer often faces plant managers reluctant to approve hipot tests. The managers ask, 'Do hipot tests damage rotating machine insulation?' This paper tries to answer this specific question. The authors discuss experience of industry experts from an extensive literature review carried out under an EPRI project. Some quasi-theoretical arguments are used to quantify possible damage to the insulation system by a hipot test. Results from recent hipot test experiments on a large number of stator coils performed under another EPRI project are analyzed. There emerges a compelling conclusion that hipot tests do not appear to cause any significant damage to the insulation system of a rotating machine stator in a serviceable condition.**

Keywords: **Rotating Machine; Insulation; Hipot test; Damage**

I. INTRODUCTION

Over-potential or high voltage withstand or hipot tests have been applied for almost a century to rotating machine windings to test the integrity of their insulation system and to assure that the electrical insulation in windings is fit for service. Hipot tests may be performed using three types of voltages: AC at the power frequency, very low frequency (VLF) at 0.1 Hz, and DC according to well-known IEEE, IEC and NEMA standards [1-5]. The hipot tests are used universally as acceptance tests for new windings or rewinds. However, not all utilities use the hipot test as a maintenance test on machines in service. In a survey for an EPRI project, a significant section (25 %) of responding utilities did not specify or use any hipot test during maintenance of machines in service [6]. This reluctance in using hipot tests for maintenance most often arises from the perception that a hipot test may fail a good working machine. A rotating machine maintenance engineer often faces plant managers reluctant to approve hipot tests. The managers ask, 'Do hipot tests damage rotating machine insulation?' Attempts have been made to answer this question in earlier papers [6, 7]. However, because of the discussion of several other important issues related to hipot tests in the same paper, this question often does not get enough prominence and is somewhat masked. This paper tries to answer this specific question, and only this

question, as clearly and definitely as possible. The authors discuss experience of industry expert engineers from an extensive literature review and the survey carried out under an EPRI project [6]. Some quasi-theoretical arguments are used to estimate possible loss of life of the insulation system in rotating machines by a hipot test. Finally results from hipot test experiments on a large number of stator coils performed under another EPRI project are analyzed to determine, if any damage to the machine insulation was caused by the hipot test [7]. These three approaches are used to arrive at a compelling conclusion that hipot tests do not appear to cause any significant damage to the insulation system of a rotating machine stator in a serviceable condition.

II. EXPERT ENGINEERS' EXPERIENCE

Hipot tests on rotating machines have been performed by many engineers both in the factory and in utility stations. The hipot test level is (2E+1) kV for the power frequency AC test [1], 1.63 (2E+1) kV for 0.1 Hz test [2], and 1.7 (2E+1) kV for DC test [3] for new windings, E being the rated line-to-line voltage. For maintenance tests on machines in service, the hipot test level is generally 75 % of the value for new machines namely (1.5E+1) kV AC or equivalent. The hipot tests are done at ambient temperatures.

A machine, which fails a maintenance hipot test, is almost always subjected to further detailed investigations, including dissection of various sections. Expert engineers have observed that a machine, which failed a hipot test, has always been found to have a poor or degraded insulation system in the examination following the failure. Experts have also experienced that a machine, which passed a hipot test, rarely fails in service [8, 9]. Several respondents to our survey of utilities under the EPRI project [6, 10] also provided similar comments. Thus hipot tests may fail marginal or poor machines and but not good machines in service.

III. THEORETICAL BASIS

The expected life L of rotating machine insulation is known to vary as inverse power n of the voltage V

$$L = k \, V^{-n} \qquad (1)$$

where k is a constant, and exponent n varies from 9 to 12, with the most often used value 10. Thus a 10 % increase in electrical stress reduces the insulation life to half [11 - 13].

The insulation in a machine experiences voltages up to the rated voltage E at operating temperature (say 105 ºC) in its expected service life (say 25 years or 219,000 h).

Using the inverse power law above, the estimated loss in life in a maintenance hipot test at voltage (1.5E + 1) kV AC (or equivalent DC or 0.1 Hz voltage) for 1 minute will be

Life lost in hipot test = $(1.5)^{10}$ minute = 58 minutes   (2)

The loss of life in a hipot test can also be estimated in another way. All coils and bars used today in machines should have the capability to pass a voltage endurance test [14]. Typically for good 13.8 kV winding coils, the voltage endurance test requires 250 hours life at 35 kV or 400 hours at 30 kV (at about 95 - 105 ºC) without failure [15]. If a 400-hour test at 30 kV represents 25 years or 219000 h life in service, then using the inverse power law a one minute hipot test at 22 kV (=1.5E+1 kV) AC ages the insulation by

219000 h * $(22/30)^{10}$ * (1 min /400 h) = 0.41 h   (3)

The above estimated loss of life in (2) and (3) above ignores the fact that the hipot test is applied at room temperature (say 35 ºC or lower) which is much lower than the operating temperature or the voltage endurance test temperature (95-105 ºC). The estimated loss of life in the hipot test will be even much shorter if this temperature difference is also taken into account.

Thus from the above theoretical considerations, the insulation in a good machine should not suffer any significant degradation during a 1 minute hipot test. As the assumptions behind the above calculations are not always considered quantitatively correct, the above arguments should be treated as qualitative or quasi-theoretical in nature.

IV. EXPERIMENTAL EVIDENCE

In another EPRI project, hipot tests at 22 kV AC or 37 kV DC (maintained for 1 minute) were performed on a large number of coil groups (each with 2 or 3 coils) in a 13.8 kV, 167 MVA hydrogenerator. The stator winding consisted of several hundred Roebel bars insulated with a synthetic-resin bonded mica-filled material [7]. These hipot test voltages represent 75% of the factory test level for new windings. Sixty (60) coil groups were divided into six sets of ten coil groups each. One set was subjected to a single AC hipot, a second set to three AC hipots, and the third set to a total of five AC hipots. Similarly, the fourth set was subjected to a single DC hipot, the fifth set to three DC hipots, and the sixth set to a total of five DC hipots. Selection of the coil groups in each set was done to make them equally aged on the basis of their electrical position between line-end to neutral-end in the winding. This

selection process was necessary to avoid possible effects due to different ageing in different sets during service. Time delays between subsequent hipot applications were introduced to minimize any effects of space charge build up on those groups subject to multiple hipots. The results of the hipots are given in Tables 1 and 2. The coils are numbered in the Tables such that 1 denotes a line-end coil and 44 the neutral-end coil.

Coil Group	Result
T1-1-40, 41, 42	Passed
T1-3-1, 2	Failed (22 kV, 15s)
T1-3-14, 15	Passed
T1-3-16, 17	Passed
T1-3-27, 28	Passed
T1-1-14, 15	Failed (22 kV, 10s)
T1-1-16, 17	Passed
T1-1-27, 28	Passed
T1-1-29, 30, 31	Passed
T3-2-14, 15	Passed

Table 1(a): AC hipot results, single application

Coil Group	Result
T2-3-2, 3	Passed
T2-3-25, 16	Passed
T1-3-29, 30,31	Passed
T1-3-40, 41,42	Passed
T2-1-2, 3	Passed
T2-1-12, 13	Passed
T2-1-17, 18	Passed
T2-1-28, 29	Passed
T2-1-30, 31	Passed
T2-1-41.42	Passed

Table 1(b): AC hipot results, three applications

Coil Group	Result
T3-2-27, 28	Failed (14 kV, first shot)
T3-2-29, 30	Passed
T2-3-17, 18	Passed
T3-2-40, 41	Passed
T2-3-28, 29	Passed
T2-3-30, 31	Passed
T1-1-1, 2	Failed (22 kV, 40 s, first shot)
T3-1-38, 39	Passed
T3-2-3, 4	Passed
T3-2-16, 17	Passed

Table 1(c): AC hipot results, five applications

In coil groups subjected to multiple hipot tests, all of the failures occurred in the first shot. Clearly the coils, which passed the first hipot, did not fail the subsequent hipots.

(Interestingly, no failures occurred when three successive hipots were applied.) This appears to suggest that hipot tests do not degrade the insulation in good coil groups.

Coil Group	Result
T1-1-34, 35	Passed
T1-1-36, 37	Passed
T1-3-7, 8, 9	Passed
T1-3-10, 11	Failed (37 kV, 10s)
T3-1-20, 21, 22	Passed
T3-1-23, 24	Passed
T1-1-10, 11	Passed
T1-1-21, 22	Passed
T1-1-23, 24	Passed
T3-2-9, 10, 11	Failed (20 kV)

Table 2(a): DC hipot results, single application

Coil Group	Result
T2-3-8, 9	Passed
T2-3-10, 11	Passed
T1-3-34, 35	Passed
T1-3-36, 37	Passed
T2-1-8, 9	Passed
T2-1-10, 11	Passed
T2-1-21, 22	Passed
T2-1-23, 24, 25	Passed
T2-1-34, 35, 36	Passed
T2-1-37, 38	Passed

Table 2(b): DC hipot results, three applications

Coil Group	Result
T3-2-34, 35	Passed
T3-2-36, 37	Passed
T2-3-21, 22	Passed
T2-3-23, 24, 25	Passed
T2-3-34, 35, 36	Passed
T2-3-37, 38	Passed
T3-1-18, 19	Passed
T3-1-25, 26	Passed
T1-1-7, 8, 9	Failed (37 kV, 50 s, first shot)
T3-2-7, 8	Passed

Table 2(c): DC hipot results, five applications

Coil Group	Result
T3-2-29, 30	Passed
T2-3-17, 18	Passed
T3-2-40, 41	Passed
T2-3-28, 29	Passed
T2-3-30, 31	Passed
T3-1-38, 39	Failed – 39 kV
T3-2-3, 4	Failed – 27 kV
T3-2-16, 17	Passed

Table 3: AC breakdown results, surviving bars previously subject to five ac hipot applications

Coil Group	Result
T3-2-34, 35	Passed
T3-2-36, 37	Passed
T2-3-21, 22	Failed – 35 kV
T2-3-23, 24, 25	Failed – 39 kV
T2-3-34, 35, 36	Failed – 40 kV, 10 s
T2-3-37, 38	Failed – 36 kV
T3-1-18, 19	Passed
T3-1-25, 26	Failed – 39 kV
T3-2-7, 8	Passed

Table 4: AC breakdown results, surviving bars previously subject to five dc hipot applications

Coil Group	Result
T3-2-18, 19	Failed – 35 kV
T3-2-25, 26	Failed – 39 kV
T3-2-31, 32, 33	Failed – 39 kV
T2-3-19, 20	Failed – 37 kV
T3-2-38, 39	Passed
T2-3-26, 27	Passed
T2-3-32, 33	Passed
T3-2-5, 6	Failed – 39 kV
T1-1-5, 6	Failed – 32 kV

Table 5: AC breakdown results, no previous hipots

Subsequent to the above hipot tests, AC breakdown tests up to a level of 40 kV AC were performed on the surviving coils of the twenty coil groups subjected earlier to five applications of AC and DC hipots. The voltage value is approximately 40% above the ac hipot level required for new windings of this voltage class. Thus, a total of eight coil groups previously subject to five AC hipots and nine coil groups subject to five DC hipots were available for this phase of the test program. A further nine coil groups, which had not undergone any hipot test, were submitted to AC breakdown testing as a control. The number of coil groups involved in this component of the

study was limited by the time available for site testing. Originally, the test plan called for those groups subject to one and three hipots to be included. Results of the tests are recorded in Tables 3, 4 and 5.

The minimum breakdown voltage for any coil group in Table 3 and 4 is 27 kV, indicating a good condition of the insulation in these coils after five AC or DC hipot tests. Also a close examination of results from Table 3, 4, and 5 indicates that those coil groups, which had not experienced any type of hipot tests (Table 5), do not have significantly higher breakdown voltage than those coil groups, which survived five AC hipots or 5 DC hipots. Thus these experiments clearly demonstrate that hipot tests do not damage an otherwise good insulation system in coil groups in stators of rotating machines.

V. CONCLUSIONS

Experience of expert engineers, theoretical arguments, and experimental results from AC and DC hipot tests on a large number of coils lead to a compelling conclusion that hipot tests do not appear to cause any significant damage to the insulation system of a rotating machine stator in a serviceable condition.

REFERENCES

1. ANSI C50.10-1990, General Requirements for Synchronous Machines.
2. IEEE Std. 433-2009, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.
3. IEEE 95-2002, Recommended Practice for Insulation Testing of AC Electric Machinery with High Direct Voltage.
4. IEC 60034-1 (2002), Rotating Electrical Machines – Part 1: Rating and Performance.
5. NEMA MG 1-2006, Motors and Generators.
6. B.K. Gupta, Greg C. Stone, and Jan Stein, Stator Winding Hipot (High Potential) Testing , 2009 IEEE Electrical Insulation Conference, Montreal, QC, May 31-June 3, 2009, IEEE Publication CFP09EEI-PRT or ISBN 978-1-4244-3916-4, pp 409-413.
7. H.G. Sedding, R. Schwabe, J. Stein, and B.K. Gupta, The Role of AC & DC Hipot Testing in Stator Winding Ageing, Proceedings of EIC/EMCW 2003, Indianapolis, Indiana, September 23-25, 2003, IEEE Publication 03CH37480, pp 455-457.
8. J. Timperley, Power Frequency Overpotential Tests on Installed Stator Windings of Rotating Electric Machines, Panel Session on "High Voltage Testing Of Rotating Machines", IEEE/PES Winter Meeting, New York, NY, February 1997, IEEE Publication 97TP119-0, pp 14-17.
9. R.E. Draper and R.H. Rehder, Overpotential Testing of Insulation in Hydro Generators, Panel Session on "High Voltage Testing Of Rotating Machines", IEEE/PES Winter Meeting, New York, NY, February 1997, IEEE Publication 97TP119-0, pp 10-13.
10. Guide for Rotating Machine Stator Winding Hipot Testing: 2007 Update, Final Report #1014908, EPRI, Palo Alto, CA: 2008.
11. Greg Stone, Edward Boulter, Ian Culbert, and Hussein Dhirani, Electrical Insulation for Rotating Machines, IEEE Press, 2004, page 46.
12. IEEE Std. 930-1987 IEEE Guide for Statistical Analysis of Electrical Insulation Breakdown Data, Clause 6.1, page 25
13. IEC 61251-2007, Electrical Insulating Materials – A.C. Voltage Endurance Evaluation.
14. IEEE Std. 1043-1996, IEEE Recommended Practice for Voltage-Endurance Testing of Form-Wound Bars and Coils.
15. IEEE 1553-2003, IEEE Standard for Voltage Endurance Testing of Form-Wound Coils and Bars for Hydrogenerators.